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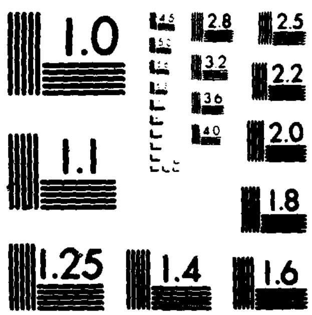

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CLOUD AND PRECIPITATION PARTICLE SIZE SPECTRA

FINAL TECHNICAL REPORT

11 June 1982

U. S. ARMY RESEARCH OFFICE

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CLOUD AND AEROSOL RESEARCH GROUP
ATMOSPHERIC SCIENCES DEPARTMENT
UNIVERSITY OF WASHINGTON
SEATTLE, WASHINGTON 98195

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Airborne measurements are described of the size distributions of cloud and precipitation particles in extratropical cyclones. Empirical expressions for the particle size distributions, and the effects of ambient conditions on these expressions, are described. The effects of the different size distributions on estimates of radar reflectivity and the mass content of cloud and precipitation particles are discussed.

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CONTENTS

CLOUD AND PRECIPITATION PARTICLE SIZE SPECTRA

1. Background

Knowledge of the size spectra of particles in clouds is important to an understanding of the mechanisms by which precipitation is produced and the effects of clouds on the radiation balance of the earth. From an applied viewpoint, information on cloud and precipitation particle size distributions is also needed in studies of aircraft icing, the effects of clouds and precipitation on the performance of various electro-optical sensors, and the erosion of the nose cones of rockets and missiles as they move at high velocities through clouds and precipitation.

While large numbers of measurements are available on the size spectra of precipitation particles reaching the ground, very little data have been available on the size spectra of particles within non-precipitating and precipitating clouds. Studies carried out under this grant have helped to remove this gap in knowledge by providing airborne measurements of particle size spectra in the widespread clouds that are associated with winter cyclones in midlatitudes.

2. Data Source

All of the data used in this study were collected as part of the University of Washington's CYCLES (CYClonic Extratropical Storms) Project carried out in the Pacific Northwest. The measurements of particle size spectra were obtained with Particle Measuring System (PMS) probes aboard the University of Washington's B-23 aircraft, NCAR's Sabreliner and Electra aircraft, and a U. S. Air Force C-130 aircraft.

An important aspect of the particle size measurements is that since they were obtained within the context of the larger CYCLES Project, they can be interpreted within the framework of the synoptic and mesoscale structures of the cyclones that have been documented in a series of papers describing CYCLES studies (see Section 4 of this report).

3. Overview of Results

Details of the results of the research carried out under this grant, and the CYCLES Project in general, have been published in a number of papers in the refereed scientific literature (see Section 4 for a list of published papers). Consequently, only a brief summary of the highlights of the results that pertain to the size spectra of cloud particles in midlatitude cyclones and some related topics will be given here.

Particle size distributions were measured in various mesoscale rainbands embedded in winter cyclones in the Pacific Northwest of the United States at temperatures ranging from -42 to 6°C. For particles greater than about 1.5 mm in diameter the size spectra followed closely an exponential size distribution of the form:

$$N(D) = N_o \exp(-\lambda D)$$

where N(D)dD is the number of particles per unit volume of air with diameters between D and D+dD, and N_o and λ are constants. Above the melting level, precipitation was mainly in the form of ice. In this region the mean particle size of the exponential distribution increased with increasing temperature. The variance (λ^{-2}) of the exponential distribution also increased with increasing temperature above the melting level, while N_0 and λ decreased with increasing temperature. Passage of the falling particles through the melting level was accompanied by a sudden decrease in the mean diameter of the particles and the variance of the exponential distribution. For particles <1.5 mm diameter, the spectra frequently deviated from the exponential distribution. A relationship between N_0 and λ of the form

$$N_0 \propto \lambda^{1.6}$$

is indicated by the data[1/].

The particle size spectra have been classified according to the degree to which they were exponential in form for diameters from 0.3 to 3.12 mm. The categories defined were:

1) Exponential (having no major deviations from the exponential form).
2) Super-exponential (having an excess of particles < 2 mm in diameter).
3) Sub-exponential (having a deficit of particles < 2 mm in diameter).
4) Non-exponential (having other deviations from the exponential form).

Stratiform-type clouds were marked by high proportions (up to 87%) of sub-exponential spectra. For convective-type clouds, the fractions of sub-exponential spectra decreased, reaching a minimum of 7% in deep convective

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1/ See J. Atmos. Sci. 36, 156-162 (1979) and J. Atmos. Sci. 37, 699-700 (1980) for details on the subject matter of this paragraph.

situations where 80% of the spectra were exponential or super-exponential.[2/]

The presence of sub- and super-exponential spectra can influence functional relationships between precipitation mass content (M), precipitation rate (R), and the radar reflectivity factor (Z). The magnitudes of these uncertainties may be assessed by examining the values of

$$R^* = R/R_o \text{ and } M^* = M/M_o$$

where R and M apply to the observed spectrum and R_o and M_o are the precipitation rate and mass content, respectively, of a corresponding hypothetical spectrum of equal slope and radar reflectivity factor, but lacking any deviation from the exponential form. Sub-exponential spectra produce values of R^* and M^* that are <1, while super-exponential spectra give values >1. In stratiform clouds, R^* ranged from 0.3 to 0.8 (indicating that the precipitation rates associated with the sub-exponential spectra observed in these clouds ranged from about 30 to 80% of those that would be associated with exponential spectra of equal radar reflectivity factor). In this environment, radar estimates of R that assume the size spectra of particles to follow an exponential distribution would be low by about 50%, while corresponding estimates of M would be low by about 60%. No systematic errors are indicated for estimates of R and M in convective clouds.[2/]

2/ For details on the subject matter of this paragraph see Paper II - 4.5 (pg 201-204) in Proceedings of the 8th Intern. Conf. on Cloud Physics, Clermont-Ferrand, France, July 1980. Further work on this subject is in progress and will shortly be submitted for publication.

Additional Note. During the course of our studies of cloud and precipitation particles, we have developed and utilized a unique dopplerized 8 mm (37.5 GHz) mobile radar unit. This radar can detect both cloud and precipitation particles, and it provides continuous and detailed information on cloud top and cloud base heights, the height of the melting level, radar reflectivities and the Doppler velocities of cloud and precipitation particles. It is not only a powerful research tool but should also be of considerable operational value. Use and further development of this radar is presently halted due to lack of funds.

4. Publications Wholly or Partially Supported by this Grant

(i) Reply to Comments on "Size distributions of precipitation particles in frontal clouds", by R. A. Houze Jr., P. V. Hobbs, D. B. Parsons and P. H. Herzegh. J. Atmos. Sci., 37, 699-700, 1980.

(ii) "Microphysics and dynamics of clouds associated with mesoscale rainbands in extratropical cyclones", by T. J. Matejka, R. A. Houze Jr. and P. V. Hobbs. Quart. J. Roy. Met. Soc., 106, 29-56, 1980.

(iii) "The mesoscale and microscale structure and organization of clouds and precipitation in midlatitude cyclones. I: A case study of a cold front," by P. V. Hobbs, et al. J. Atmos. Sci., 37, 568-596, 1980.

(iv) "The mesoscale and microscale structure and organization of clouds and precipitation in midlatitude cyclones. II: Warm-frontal clouds", by P. H. Herzegh and P. V. Hobbs, J. Atmos. Sci., 37, 597-611, 1980.

(v) "The mesoscale and microscale structure and organization of clouds and precipitation in midlatitude cyclones. III: Air motions and precipitation growth in a warm-frontal rainband", by R. A. Houze Jr., S. A. Rutledge, T. J. Matejka and P. V. Hobbs. J. Atmos. Sci., 38, 639-649, 1981.

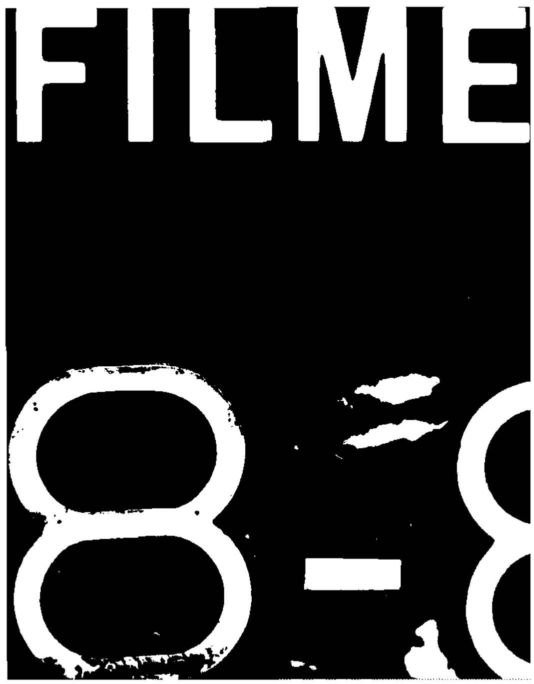
(vi) "The mesoscale and microscale structure and organization of clouds and precipitation in midlatitude cyclones. IV: Vertical air motions, precipitation growth and microphysical structures of prefrontal surge clouds and cold-frontal clouds", by P. H. Herzegh and P. V. Hobbs, J. Atmos. Sci., 38, 1771-1784, 1981.

Publications Wholly or Partially Supported by this Grant (Continued)

(vii) "Mesoscale structures in midlatitude frontal systems", by P. V. Hobbs. In Nowcasting: Mesoscale Observations and Short-Range Prediction. Proceedings of an International IAMAP Symposium, 25-28 August 1981, Hamburg, Germany. Published by the European Space Agency, pp. 29-36.

(viii) "The Use of a single Doppler radar in short-range forecasting and real-time analysis of extratropical cyclones", by T. J. Matejka and P. V. Hobbs. In Nowcasting: Mesoscale Observations and Short-Range Prediction. Proceedings of an International IAMAP Symposium, 25-28 August, 1981, Hamburg, Germany. Published by the European Space Agency, pp. 177-182.

(ix) "The mesoscale and microscale structure and organization of clouds and precipitation in mid-latitude cyclones. VI. A model for the 'seeder-feeder' process in warm-frontal rainbands", by S. A. Rutledge and P. V. Hobbs. Submitted for publication to J. Atmos. Sci.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